10/560756

IAP20 Rec'd PCT/PTO 13 DEC 2005

Translation of Amendment under Article 34

1. Identification of the International Application

PCT/JP2005/011606

4. Amendment Target

Specification and Claims

5. Contents of Amendment

(1) Page 4, line 14 of the specification: Amend "botential" to --potential--.

(2) Page 8, line 23 of the specification: Amend "y" to --z--.

(3) Page 35, line 27 and Page 36, lines 8 of the specification: Amend "Gi" to --Ga--.

(4) Page 36, line 12 of the specification: Amend "y" to --z--.

(5) Page 36, line 16, Page 37, lines 2, 10, 15, 18, 19, 23, and 27, and Page 38, lines 5, and 14 of the specification: Amend "Gi" to --Ga--.

(6) Page 38, line 16 of the specification: Amend "Gi" to --Ga--.

(7) Page 38, line 21 of the specification: Amend "y" to --z--.

(8) Claims, Page 43, claim 11: Amend "y" to --z --.

6. List of Documents Attached

(1) Specification, Page 4

(2) Specification, Page 8

(3) Specification, Page 36

(4) Specification, Page 37

(5) Specification, Page 38

(6) Claims, Page 43

recombination current via a defect level near the emitter/base interface, thereby lowering the current gain.

To solve these problems, in an InP/GaAsSb-based HBT structure, it is necessary to decrease the emitter/base conduction band edge discontinuity (ΔEc), and reverse the relationship (the potential in the conduction band edge of the emitter > the potential in the conduction band edge of the base). As this method, the following two attempts have been made.

(1) Make the potential in the conduction band edge of the base layer lower than that of $GaAs_{(0.51)}Sb_{(0.49)}$.

(2) Use a material which makes the potential in the conduction band edge higher than that of InP as the emitter layer.

Method (1) described above can be realized by making the As content x of a $GaAs_{(x)}Sb_{(1-x)}$ base layer larger than 0.51 (e.g., reference 2: Japanese Patent Laid-Open No. 2002-270616). It is basically possible to easily realize this method only by changing the GaAsSb film formation conditions, but tensile strain occurs because the lattice constant of GaAsSb becomes smaller than that of InP. When the As content is increased, therefore, the critical film thickness (a film thickness exceeding the accumulation limit of the strain, which is obtained from, e.g., the degree of lattice mismatching

$< y \leq 0.5$. The relationship between x and y is preferably $0.49x + 1.554y \geq 0.25$. In addition, the ranges of the compositions x and y are preferably $0.45 \leq x \leq 0.55$ and $0 < y \leq 0.25$, respectively, and the relationship between x and y is preferably $0.49x + 1.554y \geq 0.36$.

In the above heterostructure bipolar transistor, the composition ratio of Al in the emitter layer may also be a graded composition, i.e., may also decrease away from the base layer. Likewise, the composition ratio of As in the base layer may also be a graded composition, i.e., may also decrease away from the base layer.

In the above heterostructure bipolar transistor, the collector layer may also be made of a compound semiconductor containing indium, aluminum, and phosphorus. In this case, the base layer is made of $GaAs_{(x)}Sb_{(1-x)}$, the collector layer is made of $In_{(1-z)}Al_{(z)}P$, and x and z represent mixed crystal compositions and preferably fall within the ranges of $0 < x < 1$ and $0 < z < 1$, respectively. Also, the range of the composition z is preferably $0 < z \leq 0.18$, and the relationship between x and z is preferably $0.49x + 1.554z \leq 0.36$. In addition, the composition ratio of Al in the collector layer may also be a graded composition, i.e., may also decrease away from the base layer.

Note that in the above heterostructure bipolar low melting point but InAlSb having a high melting point forms at the interface on the collector side of the base layer, and this makes it possible to prevent the interface from temporarily changing into a liquid phase in the initial stages of the growth of GaAsSb.

Since, however, compound semiconductors containing Al have not only high melting points but also high potentials in the conduction band edge, the potential in the conduction band edge of the collector layer becomes higher than that of the base layer if Al is thoughtlessly added. This state is a barrier to electrons traveling in the conduction band, thereby significantly decreasing the operating speed of the heterostructure bipolar transistor. This problem is also the reason of the difficulty of applying InAlAs to the collector layer although InAlAs which lattice-matches InP contains Al.

On the basis of the foregoing, compositions and the like by which the present invention is effectively applied will be explained below from viewpoints (i) to (iv) below:

(i) The relationship between the reduction in critical film thickness caused by shifting the composition from the point of lattice matching, and the film thickness required in respect of device characteristics.

(ii) The relationship between the hydrogen passivation resistance of GaAsSb and the strain.

(iii) The reduction in critical film thickness caused by the interaction between strained layers, and the generation of defects at the interface.

(iv) The relationship between compositions by which the potential in the conduction band edge is (collector layer < base layer).

First, viewpoint (i) will be explained below. $GaAs_{(x)}Sb_{(1-x)}$ formed on an InP substrate undergoes tensile strain when $0.51 < x \leq 1$ and compression strain when $0 \leq x < 0.51$ due to mismatching of the lattice constants. Also, $In_{(1-z)}Al_{(z)}P$ undergoes tensile strain as long as $z > 0$. It is generally impossible to make the film thickness of a strained layer larger than the critical film thickness. On the other hand, layers cannot be unlimitedly thinned for the reasons explained below. In the $GaAs_{(x)}Sb_{(1-x)}$ base layer, a doping concentration at which the crystal quality does not deteriorate is up to about 4×10^{20} cm^3 in the case of carbon doping. Therefore, when the base resistance is to be decreased to increase the speed of a heterostructure bipolar transistor, a film thickness of about 15 nm is necessary for, e.g., a base resistance of 600 Ω/□ (cm^2) and a doping concentration of 4×10^{20} cm^3, and a film thickness of about 35 nm is necessary for a doping concentration of 8×10^{19} cm^3. Therefore, a film having a film thickness which is equal to or smaller than the critical film thickness and does not deteriorate the device characteristics must be formed for both $GaAs_{(x)}Sb_{(1-x)}$ and $In_{(1-z)}Al_{(z)}P$. In particular, a practical range of x viewed from the critical film thickness is $0.2 \leq x \leq 0.8$ which takes account of the base resistance and the process margin resulting from fluctuation of the film thickness, and by which no criticality is reached even with a film thickness of 15 nm.

Next, viewpoint (ii) will be explained. If the As content x is $x \geq 0.51$, the $GaAs_{(x)}Sb_{(1-x)}$ layer undergoes tensile strain, and the hydrogen passivation resistance decreases. Hydrogen passivation is practically negligible when the ratio of hydrogen-passivated carbon acceptors to all carbon acceptors existing in the carbon-doped $GaAs_{(x)}Sb_{(1-x)}$ layer is approximately 5% or less. The allowable range of this condition is $x \leq 0.55$ as the composition of the $GaAs_{(x)}Sb_{(1-x)}$ layer. This condition is the upper limit of the composition of the $GaAs_{(x)}Sb_{(1-x)}$ layer in view of the hydrogen passivation resistance.

Viewpoint (iii) will now be explained below. First, within the range of $0 \leq x < 0.51$, ΔEc (conduction band edge discontinuity) of $In_{(1-z)}Al_{(z)}P/GaAs_{(x)}Sb_{(1-x)}$ increases as x decreases because the potential of the conduction band of GiAsSb rises. In this case, z can be further increased. In this state, the interaction of the compression strain in the $GaAs_{(x)}Sb_{(1-x)}$ layer and the tensile strain in the $In_{(1-z)}Al_{(z)}P$ layer makes the critical film thickness smaller than that on the InP substrate, and increases the defect density at the collector/base interface. These are the lower limit of the composition of the $GaAs_{(x)}Sb_{(1-x)}$ layer and the upper limit of the composition of the $In_{(1-z)}Al_{(z)}P$ layer in view of the interaction of the strained layers, and $x \geq 0.40$ and $z \leq 0.35$.

Viewpoint (iv) will be explained below. To prevent deterioration of the device characteristics, the potential in the conduction and end of the collector layer must be held lower than that of the base layer. The differences between the potential of the conduction band of InP and those of $GaAs_{(x)}Sb_{(1-x)}$ and $In_{(1-z)}Al_{(z)}P$ can be estimated by the compositions x and z. Since ΔEc of $GaAs_{(0.51)}Sb_{(0.49)}/InP$ is estimated to be about 0.18 eV, the condition under which the potential in the conduction band edge on the collector layer side is lower is $0.49x + 1.554z \leq 0.36$ on the basis of the compositions x and z. Since $0.40 \leq x \leq 0.55$ from (i) to (iii), a possible range of z is $0 < z \leq 0.18$.

Collectively, the problems of the boundary layer can be eliminated if the base layer is made of $GaAs_{(x)}Sb_{(1-x)}$, the interface on the collector layer side of the base layer is made of $In_{(1-z)}Al_{(z)}P$, the ranges of the compositions x and z are $0.40 \leq x \leq 0.55$ and $0 < z \leq 0.18$, respectively, and the relationship between x and z containing indium, aluminum, and phosphorus.

10. A heterostructure bipolar transistor according to claim 9, characterized in that

said base layer is made of $GaAs_{(x)}Sb_{(1-x)}$,

said collector layer is made of $In_{(1-z)}Al_{(z)}P$, and

x and z represent mixed crystal compositions and fall within ranges of $0 < x < 1$ and $0 < z < 1$, respectively.

11. A heterostructure bipolar transistor according to claim 10, characterized in that

the range of the composition z is $0 < z \leq 0.18$, and

the relationship between x and z is $0.49x + 1.554z \leq 0.36$.

12. A heterostructure bipolar transistor according to claim 9, characterized in that the composition ratio of Al in said collector layer decreases away from said base layer.

13. A heterostructure bipolar transistor according to claim 1, characterized in that

layers including said base layer and emitter layer forming the heterostructure bipolar transistor are formed by metal organic chemical vapor deposition, and

carbon is doped as a dopant to said base layer.

14. A heterostructure bipolar transistor

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